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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

PRELIMINARY DATA ON THE EFFECTS OF ALTITUDE AND INLET-PRESSURE DISTORTIONS ON STEADY-STATE AND SURGE FUEL FLOW OF THE J57-P-1 TURBOJET ENGINE

By Robert J. Lubick, William R. Meyer, and Lewis E. Wallner

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
WASHINGTON
JAN 21 1955

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FOREWORD

To permit expeditious transmittal of performance data to those concerned, figures of "preliminary data" are presented herein. Preliminary data are test data that have not received the complete analysis and extensive cross-checking normally given a set of NACA data before release.

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SUMMARY

An investigation to determine the effects of altitude and inlet-pressure distortions on the steady-state and surge characteristics of the J57-P-1 two-spool turbojet engine is being conducted in the altitude wind tunnel at the NACA Lewis laboratory. Steady-state performance and surge fuel flows were obtained with a uniform inlet distribution at altitudes of 35,000 and 50,000 feet at a flight Mach number of 0.8. In addition, similar data were obtained with one circumferential and three radial engine-inlet total pressure distortions at an altitude of 35,000 feet.

As the altitude was increased from 35,000 to 50,000 feet for the uniform inlet pressure distribution, the fuel-flow margin between steady-state and surge was reduced considerably for both compressor bleed positions. Total-pressure distortions of the magnitudes investigated had very little effect on the steady-state fuel flow. The circumferential distortion appreciably decreased the surge fuel-flow margin in the high-speed region with the intercompressor bleeds closed while the small radial distortions investigated had little if any effect on the surge fuel-flow line.

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, an investigation is being conducted in the Lewis altitude wind tunnel to determine the steady-state and transient performance of the J57-P-1 turbojet engine. Preliminary data on the steady-state performance and operating characteristics of the engine are presented in references 1 and 2. These data covered a range of rotor speeds, various bleed positions, and altitudes up to 50,000 feet at a flight Mach number of 0.8.

Further preliminary data on the effect of inlet-pressure distortion on both the steady-state and surge characteristics are presented in reference 3. The conditions covered by this report included one circumferential pressure distortion and three small radial distortions, at altitudes of both 35,000 and 50,000 feet at a flight Mach number of 0.8. The data of reference 3 are concerned primarily with the steady-state compressor pressure ratio and the pressure ratio at which engine surge occurred during transient operation. The fuel-flow data associated with these pressure ratios - both the steady-state values and the surge fuel flow values - for an altitude of 35,000 feet are presented herein. The effect of altitude on the steady-state and surge limit fuel-flow data are presented for only the uniform inlet pressure distribution at altitudes of 35,000 and 50,000 feet and a flight Mach number of 0.8. All data were obtained over the complete operable range of engine speeds and with the compressor bleeds both open and closed. 3648

APPARATUS

Engine and Installation

A cross-sectional view of the J57-P-1 two-spool turbojet engine is shown in figure 1. The inner spool consists of a seven-stage axial-flow compressor connected by a hollow shaft to a single-stage shrouded turbine. The outer spool consists of a nine-stage axial-flow compressor and a two-stage shrouded turbine connected by a shaft inside of and concentric with the hollow shaft of the inner spool. Rated inner-spool speed is approximately 9600 rpm. The combustor is of the cannular type having eight tubular liners each with six duplex fuel-spray nozzles.

The engine is equipped with two compressor bleed ports that permit the bleeding of air from the discharge of the outer compressor in order to avoid outer compressor surge. Opening and closing of the compressor bleeds is scheduled with outer-spool speed and engine-inlet temperature. This schedule is such that bleed actuation occurs between outer-spool speeds of about 5000 and 5600 rpm for engine-inlet temperatures of -30° and 120° F, respectively.

The turbojet engine was mounted on a wing section that spanned the test section of the altitude wind tunnel. Atmospheric air was dried, refrigerated, and throttled to the desired pressure level before being supplied to the engine by means of inlet ducting. Automatic bleed valves in the inlet ducting were used to maintain the ram pressure at the desired level during transient engine operation.

Instrumentation

Instrumentation used to measure steady-state engine performance is indicated in figure 1. In addition, engine fuel flow, inner compressor speed, and engine-inlet total pressure were measured on a multiple-channel oscillograph both during steady-state and transient operation. The presence of rotating stall was indicated by oscilloscope observations of compressor inner-stage pressure transducer and hot-wire-anemometer signals.

Types of Inlet-Pressure Distortion

The inlet-pressure distortions were produced by screen segments installed at the engine inlet 13 inches upstream of the inlet guide vanes as indicated in figure 2. In order to support the fine mesh screens, a 1/4-inch-mesh screen was placed over the entire annulus. The uniform inlet total-pressure distribution is therefore the profile existing behind this screen.

The configurations and sizes of screens are described in the following table and their location shown in figure 3:

Configuration	Type of Distortion	Size of Screen (In addition to the 1/4-in. mesh backing screen)
Undistorted	Uniform	None
A	Circumferential	0-#10-#20-#30 mesh
B	Radial	0-#7-#10 mesh
C	Radial	0-#10-#16 mesh
D	Inverse radial	#10-#7- 0 mesh

PROCEDURE

Data were obtained at a flight Mach number of 0.8 at an altitude of 35,000 feet for the uniform inlet-pressure distribution, the circumferential pressure distortion, and the three radial pressure distortions. Data were also obtained for the uniform inlet-pressure distribution at 50,000 feet and a flight Mach number of 0.8. The surge characteristics were determined over the complete range of rotor speeds with the maximum speed operating limit being limiting turbine-inlet temperature.

The compressor bleeds were manually operated for this investigation so that the bleed valves could be held in either the open or closed position, independent of the normal bleed schedule.

The standard engine fuel control was replaced for this investigation with a special fuel control to permit introduction of step changes in fuel flow. The standard fuel system (consisting of a primary and secondary flow system) was also altered to permit operation with either the primary or secondary flow system only.

For each engine-inlet configuration, the steady-state operating line and engine surge line were determined for the engine with the standard exhaust-nozzle area. A series of various size step changes in fuel flow were introduced to determine the maximum amount of fuel flow allowable to permit surge-free operation from a given spool speed. For each step change in fuel flow, the performance parameters were recorded on transient instrumentation.

RESULTS

Data presented in this report were obtained for two engines of the J57-P-1 model. The effect of altitude was obtained for engine A (Serial No. P-420150) for a uniform inlet-pressure distribution and the effect of inlet-pressure distortion was obtained for engine B (Serial No. P-420210) at one altitude.

Effect of Altitude

The effect of altitude on steady-state operation and fuel-flow surge limits (engine A) are presented in figures 4 to 8 at a flight Mach number of 0.8 for two compressor bleed positions and a uniform inlet-pressure distribution. Comparison of the fuel-flow surge limits with the steady-state operating line for altitudes of 35,000 and 50,000 feet are presented in figures 6 and 7, respectively. The fuel-flow surge line is established by the maximum value of fuel flow that could be introduced without encountering engine surge. The surge fuel-flow lines of figures 6 and 7 are presented in figure 8 for a direct comparison of the effect of altitude for compressor bleeds open and closed. As the altitude was increased from 35,000 to 50,000 feet, the steady-state fuel flow was increased and the surge-limited fuel flow was decreased, resulting in a considerable reduction in the margin between steady-state operation and surge.

Effect of Inlet Distortions

The shape and magnitude of the total-pressure distortions imposed on the engine at the inlet are presented in figures 9 and 10. Part (a) of each figure presents the pressure distortion at rated speed and, part (b) shows the variation in distortion with engine speed. It should be noted that the maximum radial distortion at rated speed has local pressure deviations of only 2 or 3 percent in the tip region and about
3648 7 percent in the hub region.

The effect of inlet-pressure distortions on the speed match between the two spools, the steady-state fuel-flow operating line, and the fuel-flow surge limits at an altitude of 35,000 feet and a flight Mach number of 0.8 are shown in figures 11 to 15 for engine operation with compressor bleeds open, and figures 16 to 20 for compressor bleeds closed (engine B).

With compressor bleeds open and for the magnitudes of distortions investigated, the speed match between the two spools (fig. 11) and the steady-state fuel-flow operating line (fig. 12) remained essentially unaltered. Figure 13 presents the fuel-flow surge limits and the steady-state operating line for the uniform inlet-pressure distribution. The fuel-flow surge limits for the circumferential distortion are compared with the undistorted surge line in figure 14 and the fuel-flow surge lines for the three small radial distortions are compared with the undistorted surge line in figure 15. In general, the inlet-pressure distortions had little effect on the fuel-flow surge line with the compressor bleeds open.

For compressor bleeds closed, the speed match between the two spools (fig. 16) and the steady-state fuel-flow operating line (fig. 17) were unaffected except that the steady-state rotating stall region for the circumferential distortion (7300 to 8700 rpm) is considerably larger than for the uniform inlet-pressure distribution (7300 to 7900 rpm). Comparison of the undistorted fuel-flow surge line (fig. 18) and the surge line for the circumferential distortion (fig. 19) shows a substantial reduction in fuel-flow surge margin for the circumferential distortion. Comparison of the fuel-flow surge lines for the radial distortions (fig. 20) and the undistorted surge line shows very little effect, as was the case for compressor bleeds open. As was previously mentioned, however, the magnitude of radial distortions investigated was relatively small and larger gradients, particularly in the tip region, might have a larger effect.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, January 13, 1955

REFERENCES

1. Bloomer, Harry E., and Miller, Robert R.: Preliminary Altitude Performance Characteristics of the J57-P-1 Turbojet Engine with Fixed-Area Exhaust Nozzle. NACA RM SE54D30, 1954.

2. Wallner, Lewis E., and Saari, Martin J.: Preliminary Altitude Operational Characteristics of a J57-P-1 Turbojet Engine. NACA RM SE54C31, 1954.

3. Wallner, Lewis E., Lubick, Robert J., and Einstein, Thomas H.: Preliminary Data on the Effects of Inlet Pressure Distortions on the J57-P-1 Turbojet Engine. NACA RM SE54K19, 1954.

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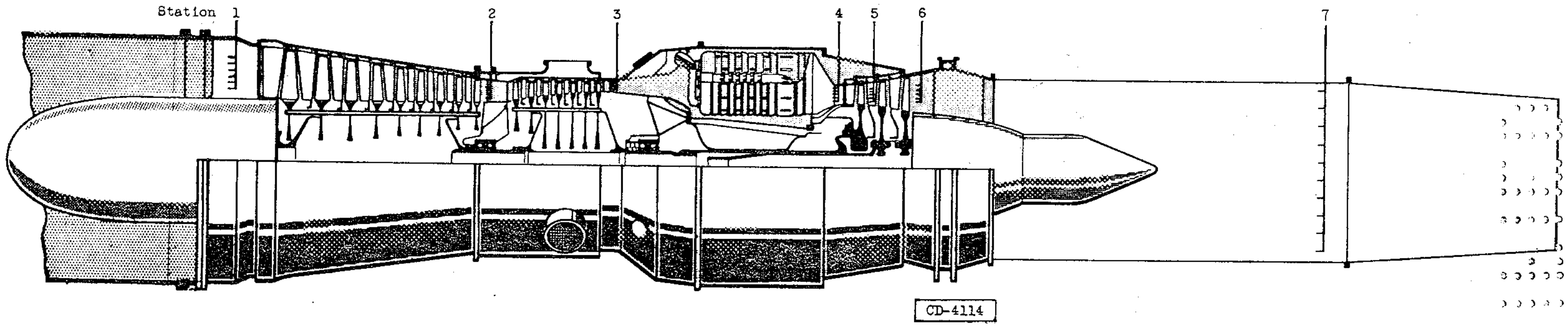

Station	Number of total pressure probes	Number of static pressure probes	Number of thermocouple probes
1	42	16	16
2	24	-	12
3	20	-	12
4	18	-	8
5	16	-	-
6	24	8	24
7	24	4	24

Figure 1. - Schematic diagram of J57-P-1 turbojet engine showing location and amount of steady-state instrumentation.

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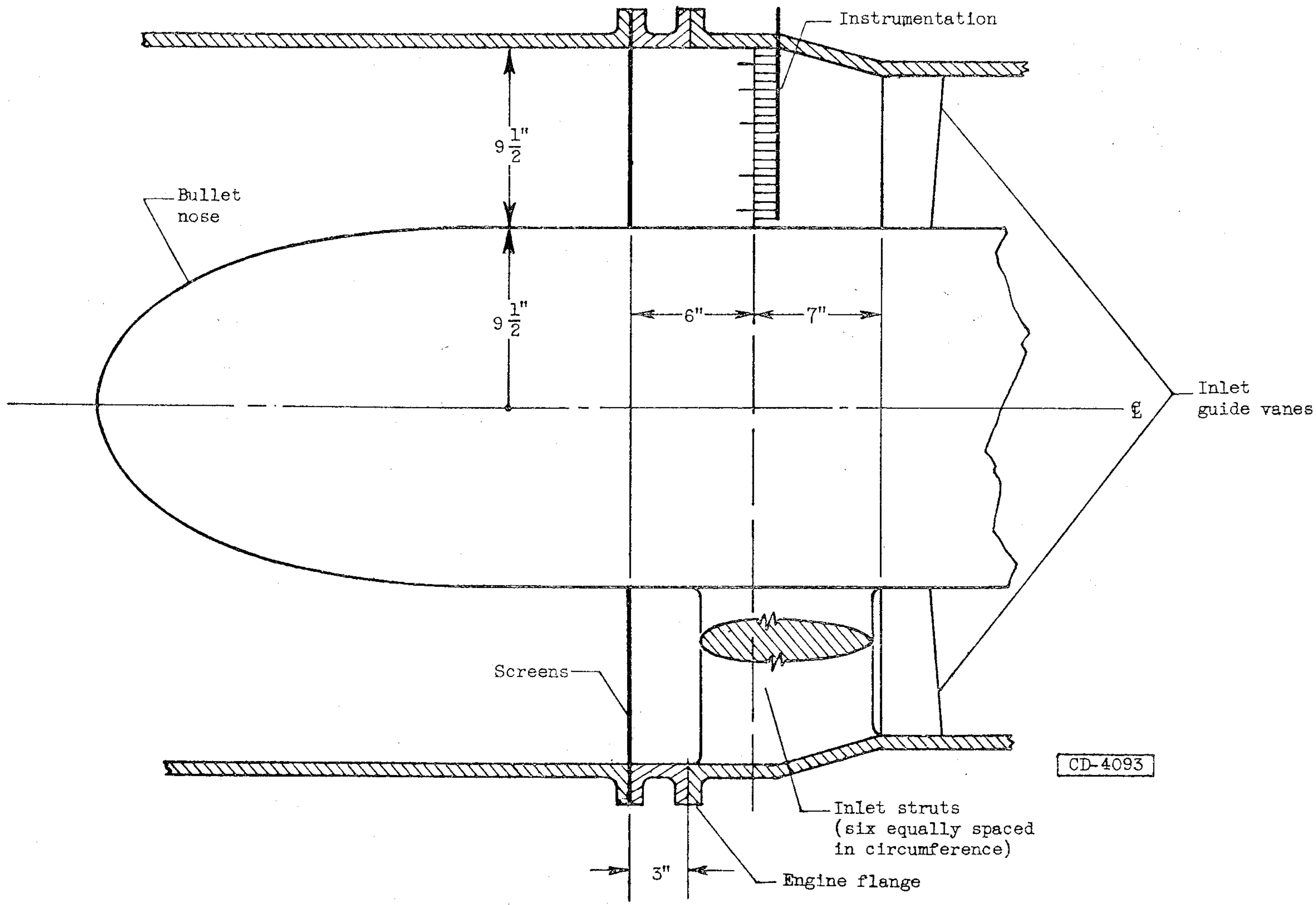

Figure 2. - Location of distortion screens and inlet instrumentation.

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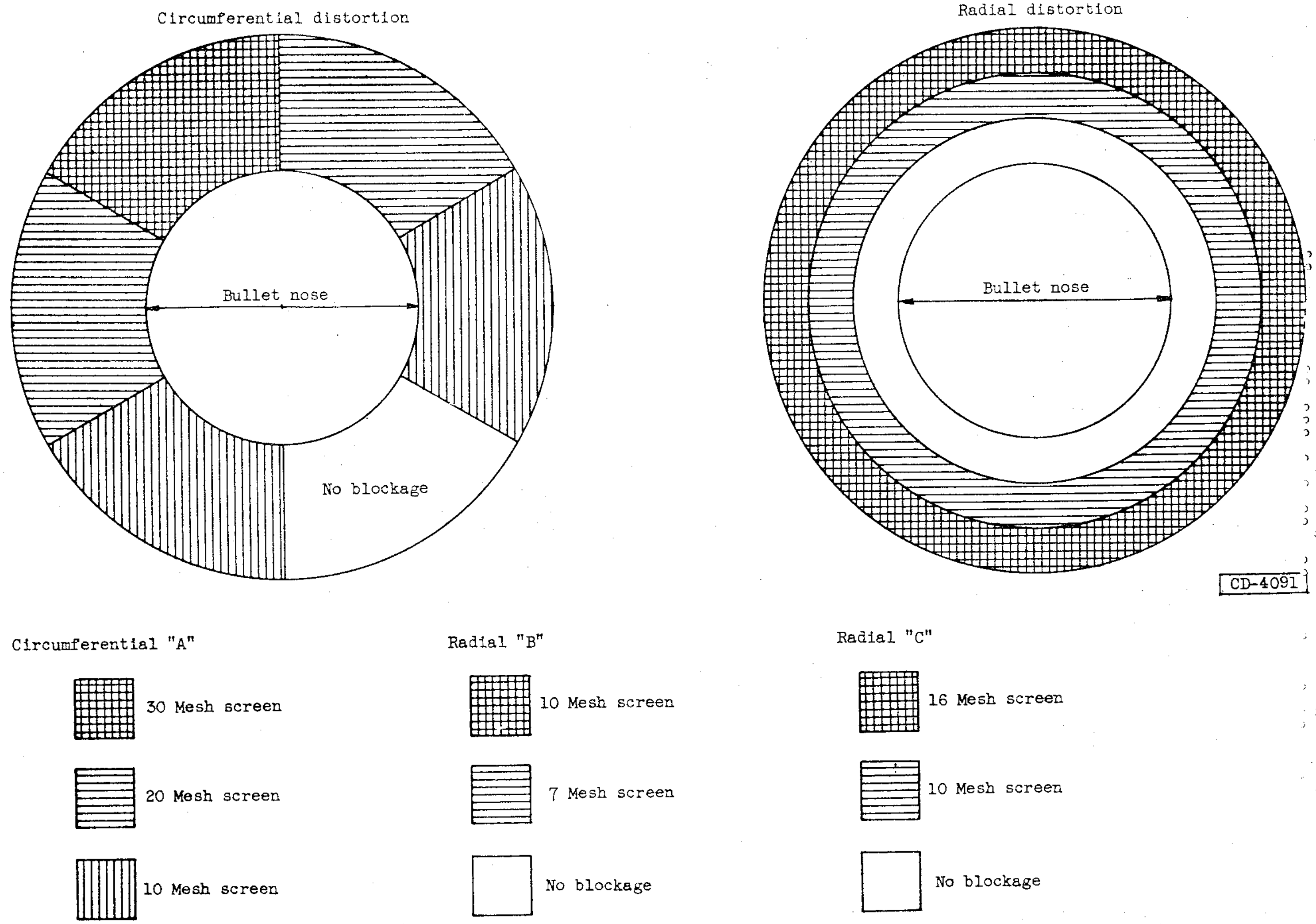

(Note: Distortion screens were supported on a 1/4" mesh which spanned the inlet annulus).

Figure 3. - Sketch of screen segments for inlet distortion investigation.

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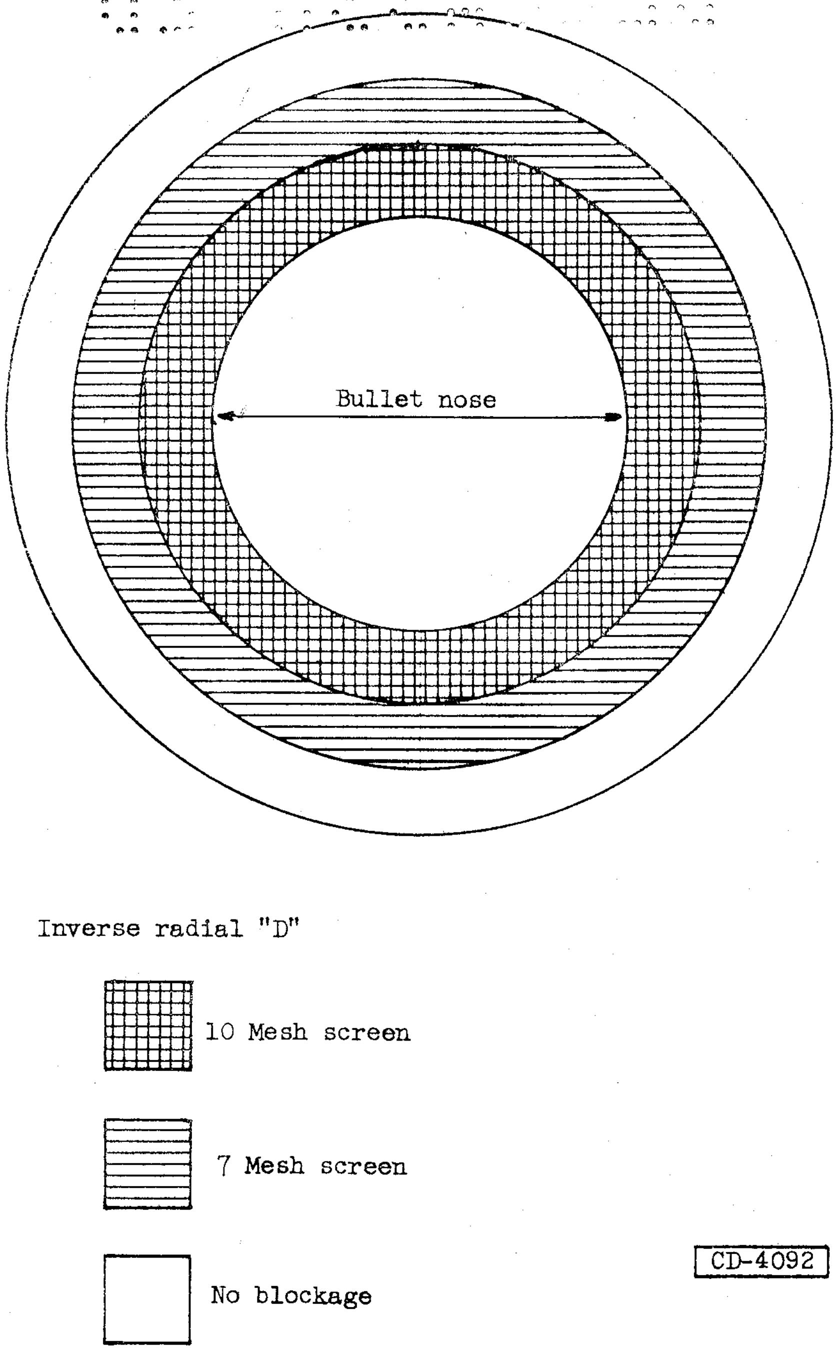
Inverse radial distortion



(Note: Distortion screens were supported on a 1/4" mesh which spanned the inlet annulus).

Figure 3. - Concluded. Sketch of screen segments for inlet distortion investigation.

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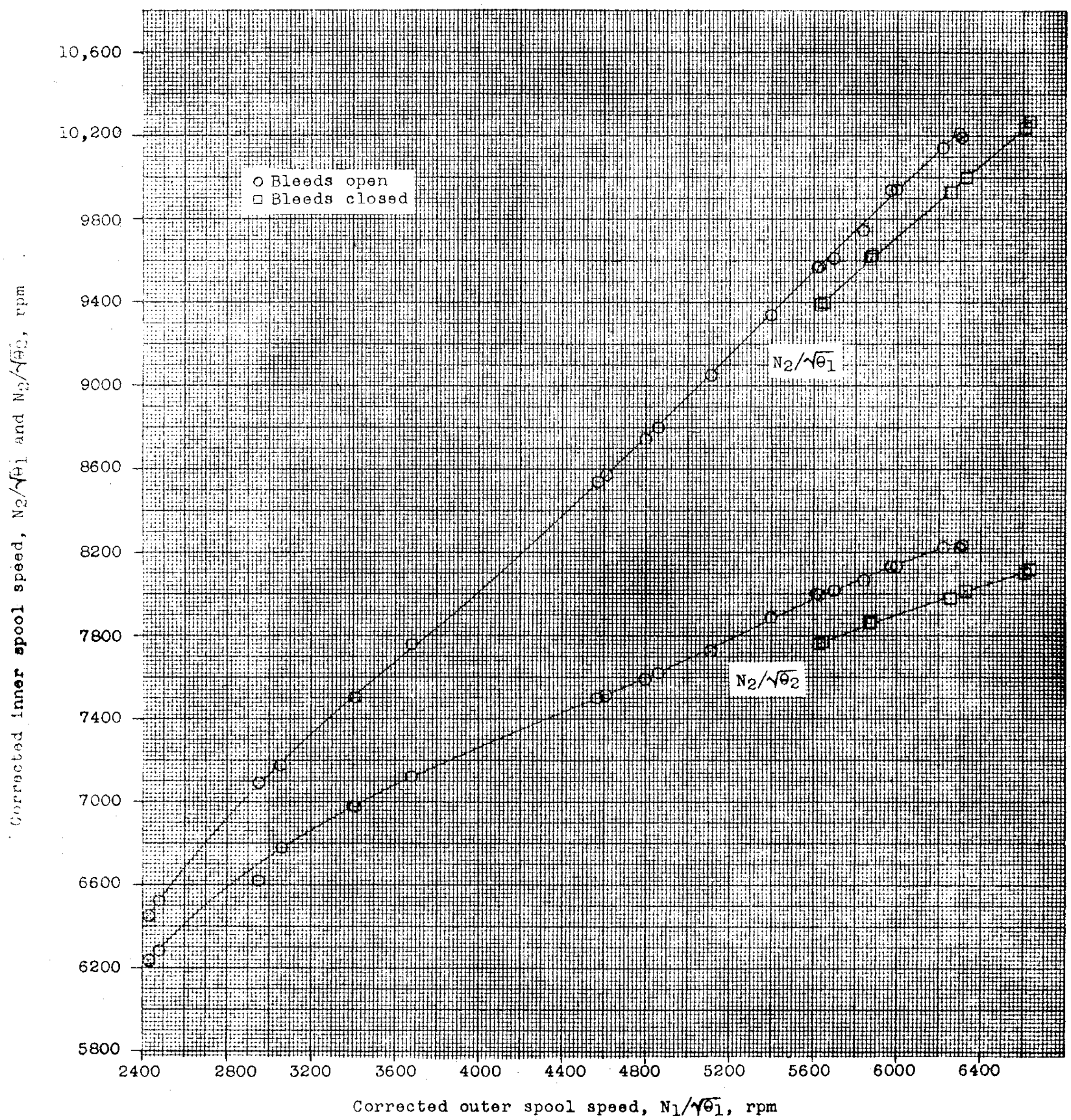

Figure 4. - Variation of corrected inner spool speed with corrected outer spool speed for uniform inlet pressure distribution. Altitude 35,000 feet, flight Mach number 0.8. Engine A.

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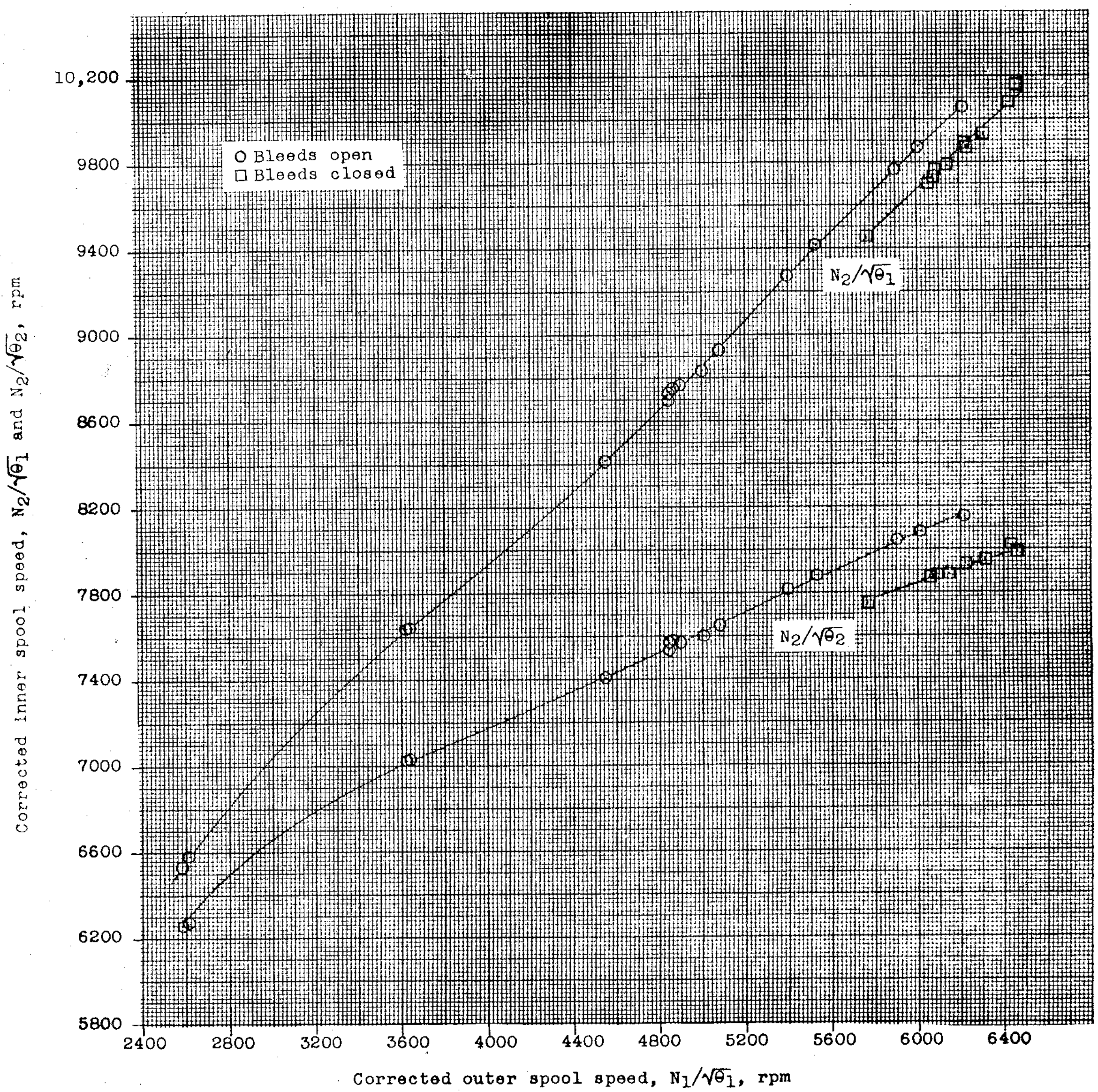

Figure 5. - Variation of corrected inner spool speed with corrected outer spool speed for uniform inlet pressure distribution. Altitude 35,000 feet, flight Mach number 0.8. Engine A.

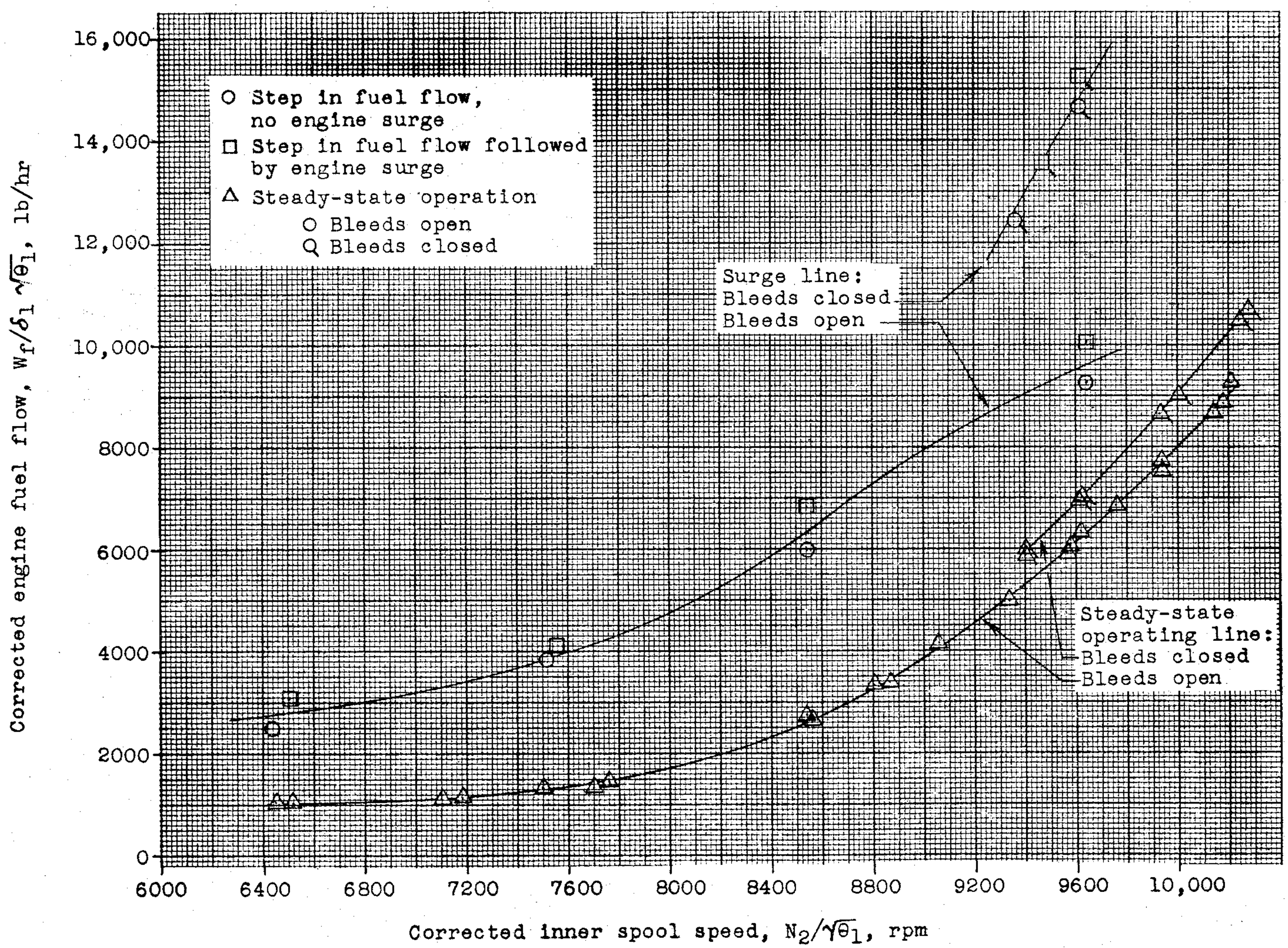

Figure 6. - Comparison of engine fuel flow surge limits with steady-state operating line for two compressor bleed positions. Uniform inlet pressure distribution. Altitude 35,000 feet, flight Mach number 0.8. Engine A.

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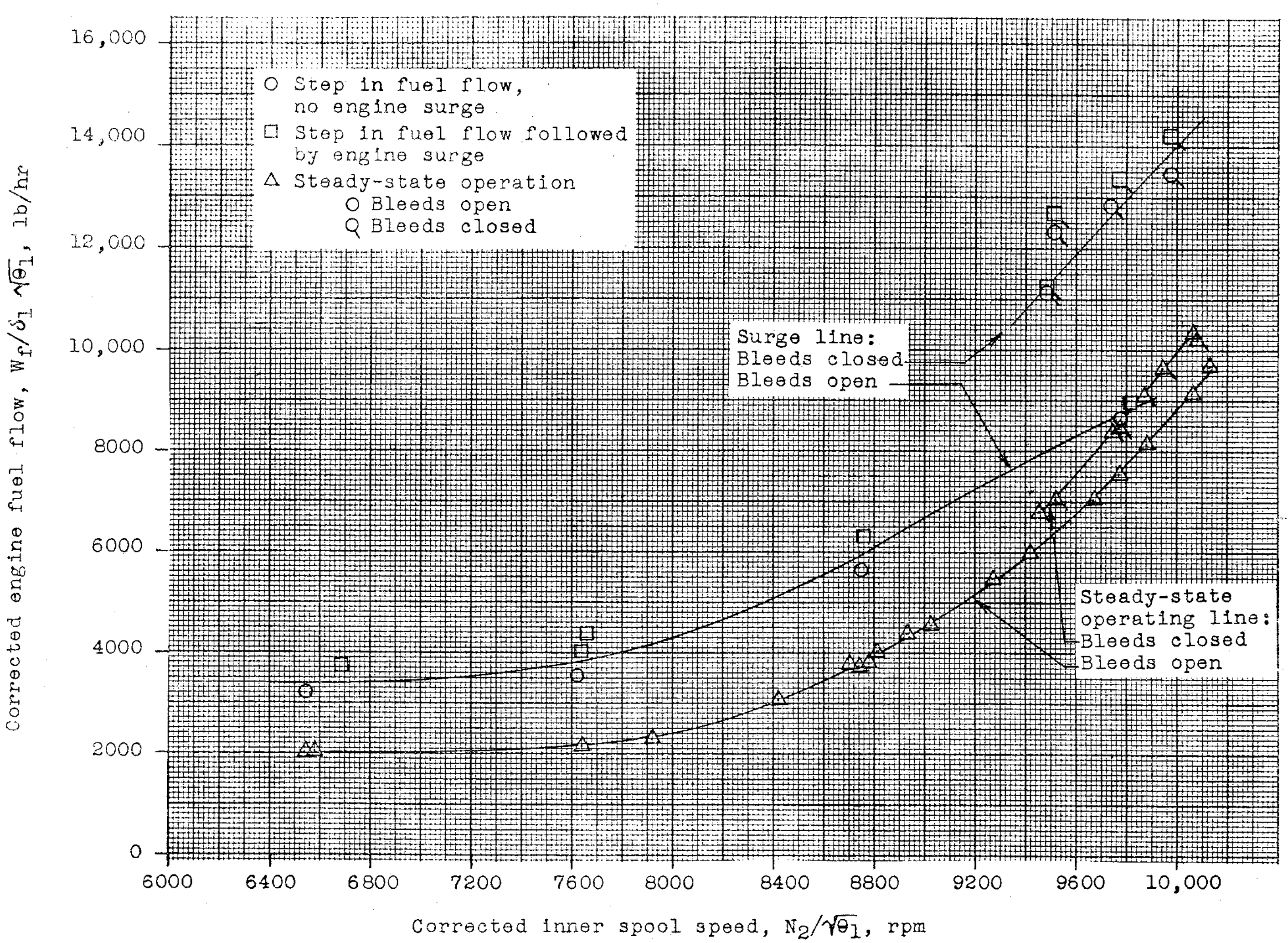

Figure 7. - Comparison of engine fuel flow surge limits with steady-state operating line for two compressor bleed positions. Uniform inlet pressure distribution. Altitude 50,000 feet, flight Mach number 0.8. Engine A.

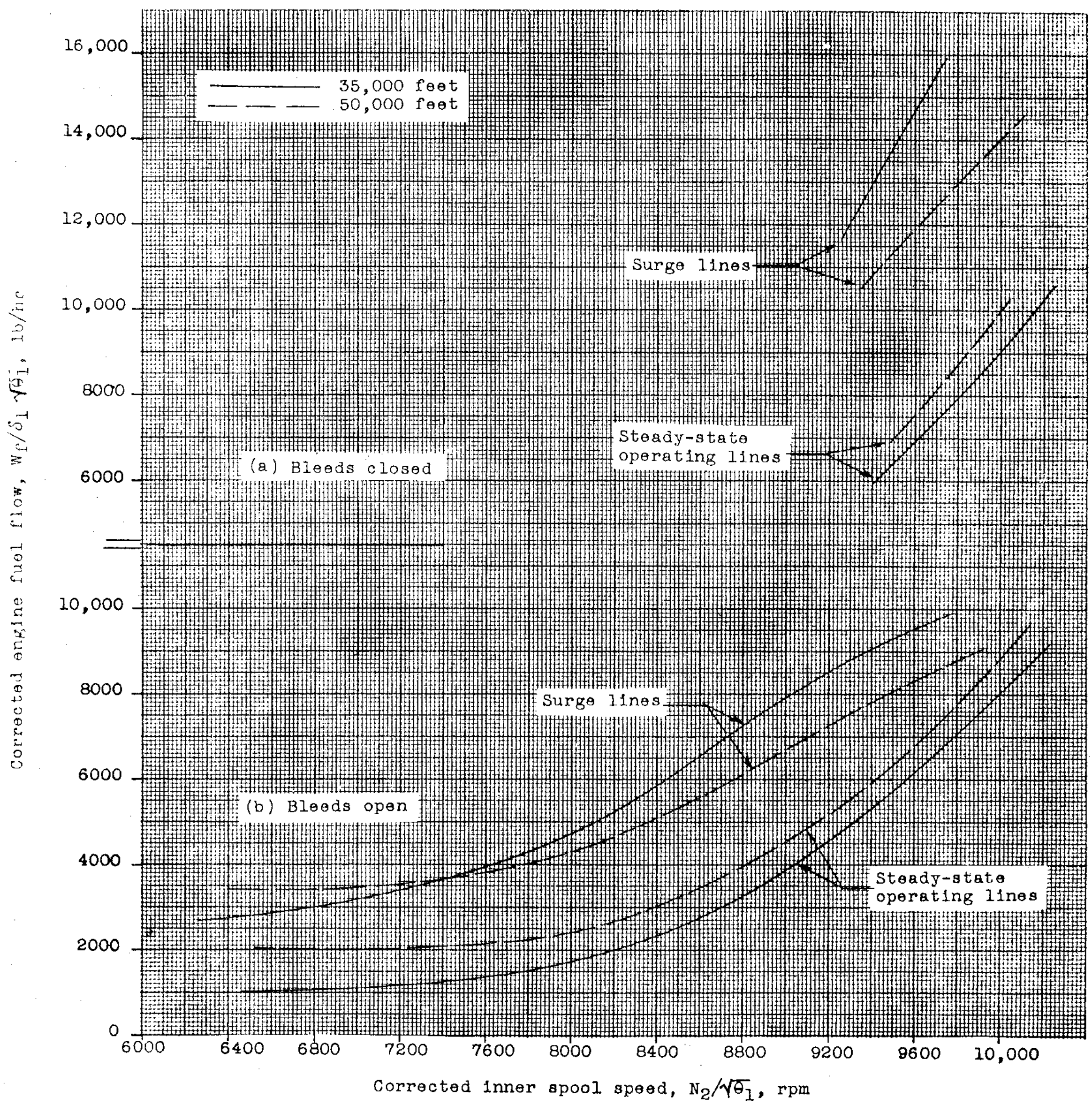

Figure 8. - Effect of altitude on engine fuel flow surge limits for two compressor bleed positions. Uniform inlet pressure distribution. Flight Mach number 0.8. Engine A.

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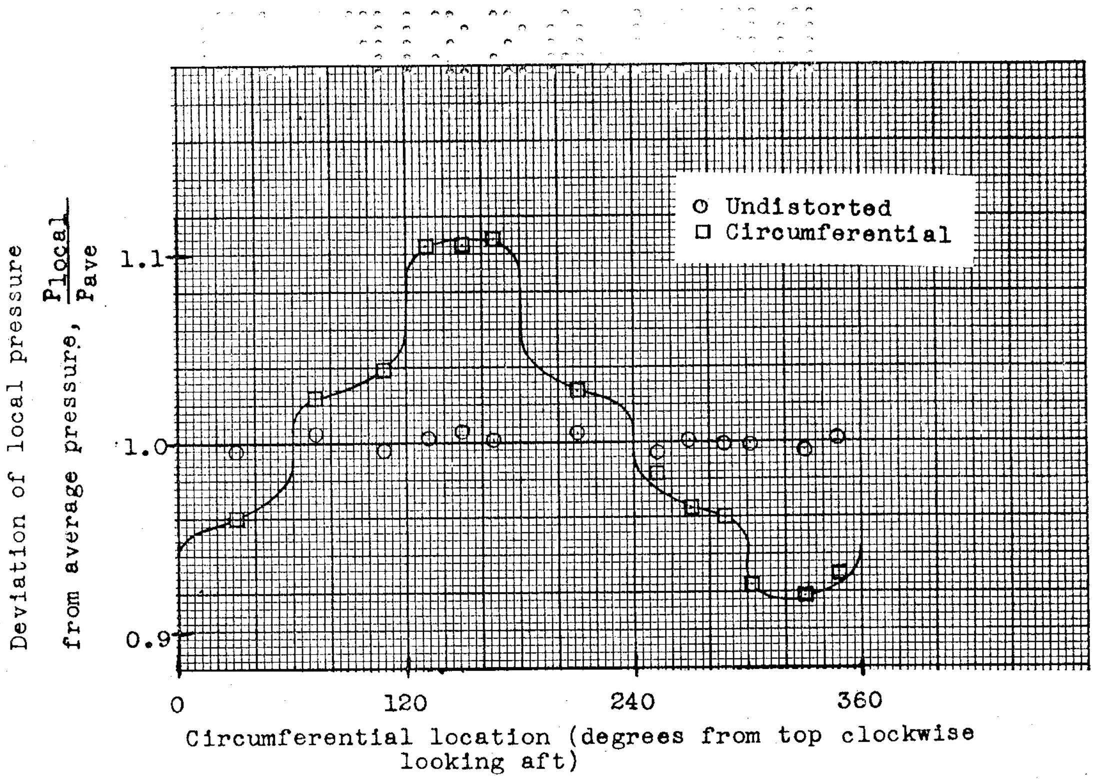

Figure 9(a). Typical circumferential total pressure profile.
Corrected engine speed, 100% of rated.

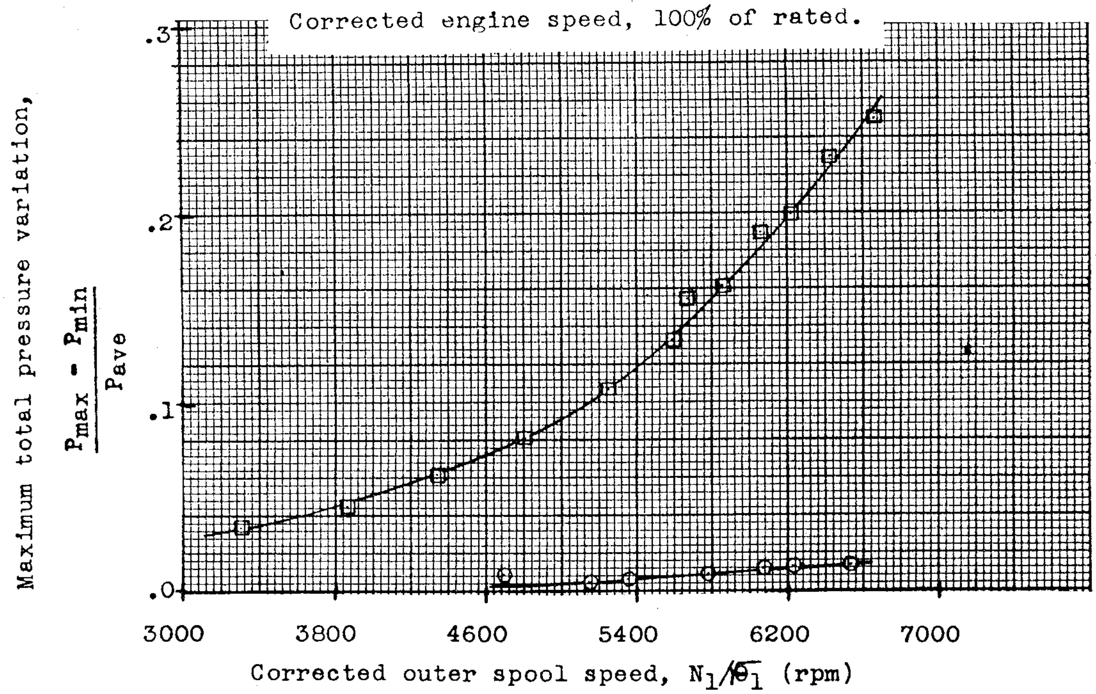

Figure 9(b). Effect of outer compressor corrected speed on the circumferential total pressure gradients. Altitude, 35,000 feet; flight Mach number, 0.8.

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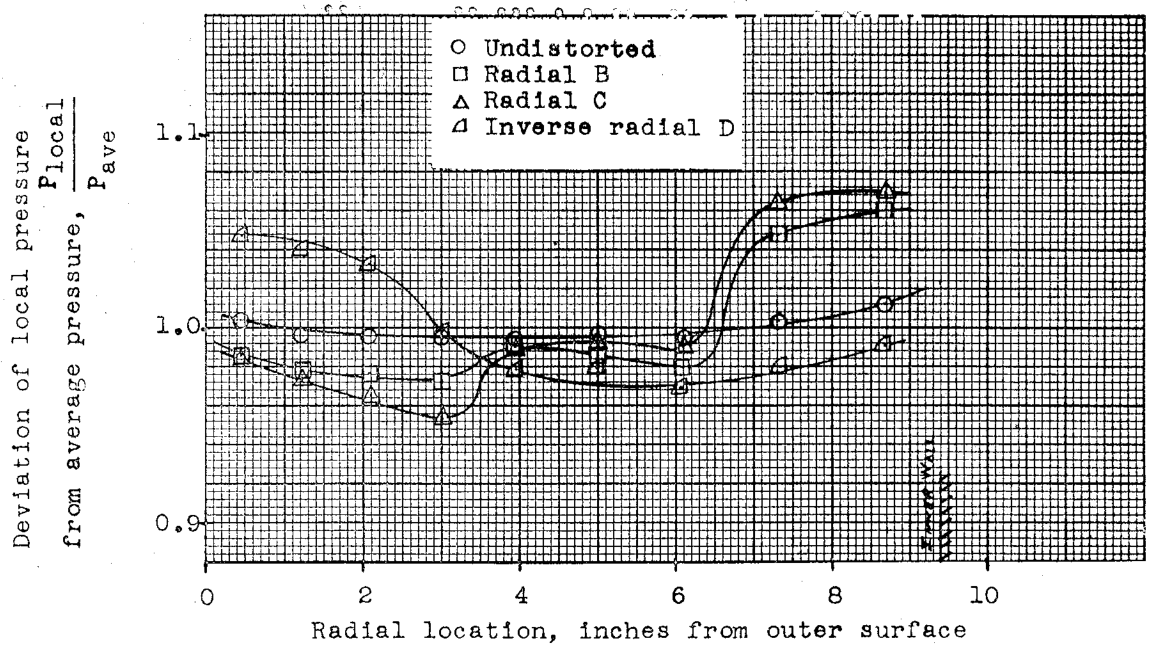

Figure 10(a). Typical radial total pressure profiles. Corrected engine speed, 100% of rated.

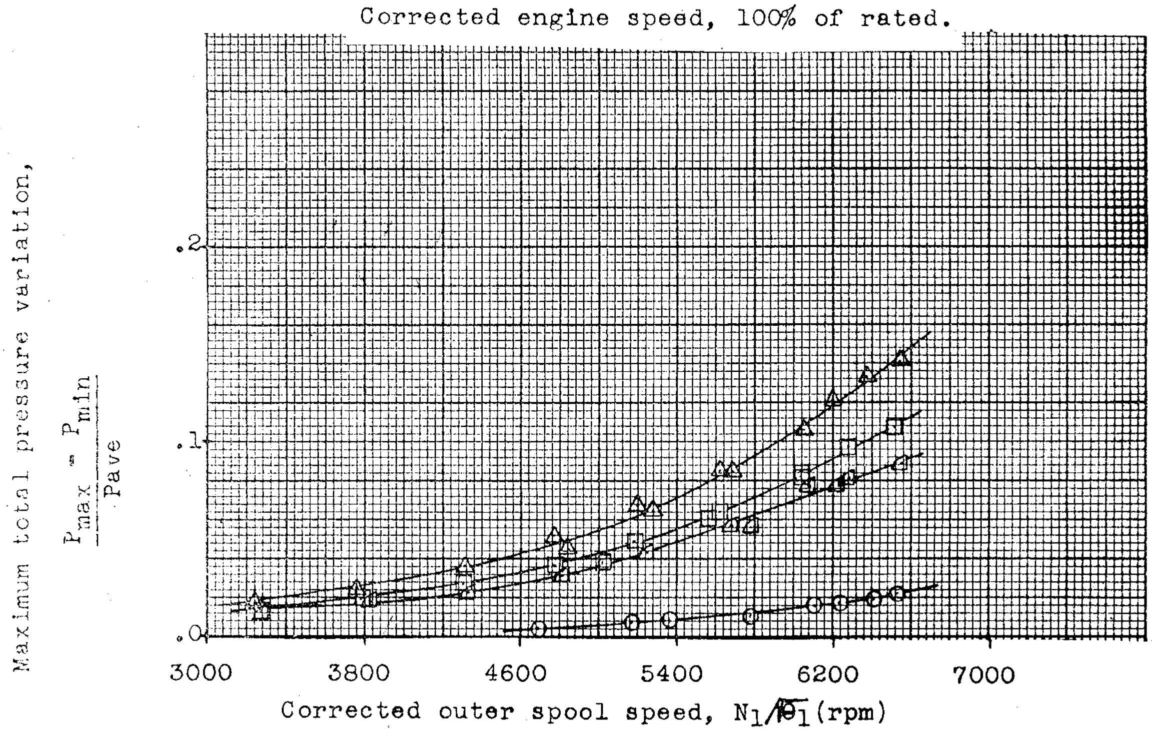

Figure 10(b). Effect of outer compressor corrected speed on the radial total pressure gradients. Altitude, 35,000 feet; flight Mach munber, 0.8.

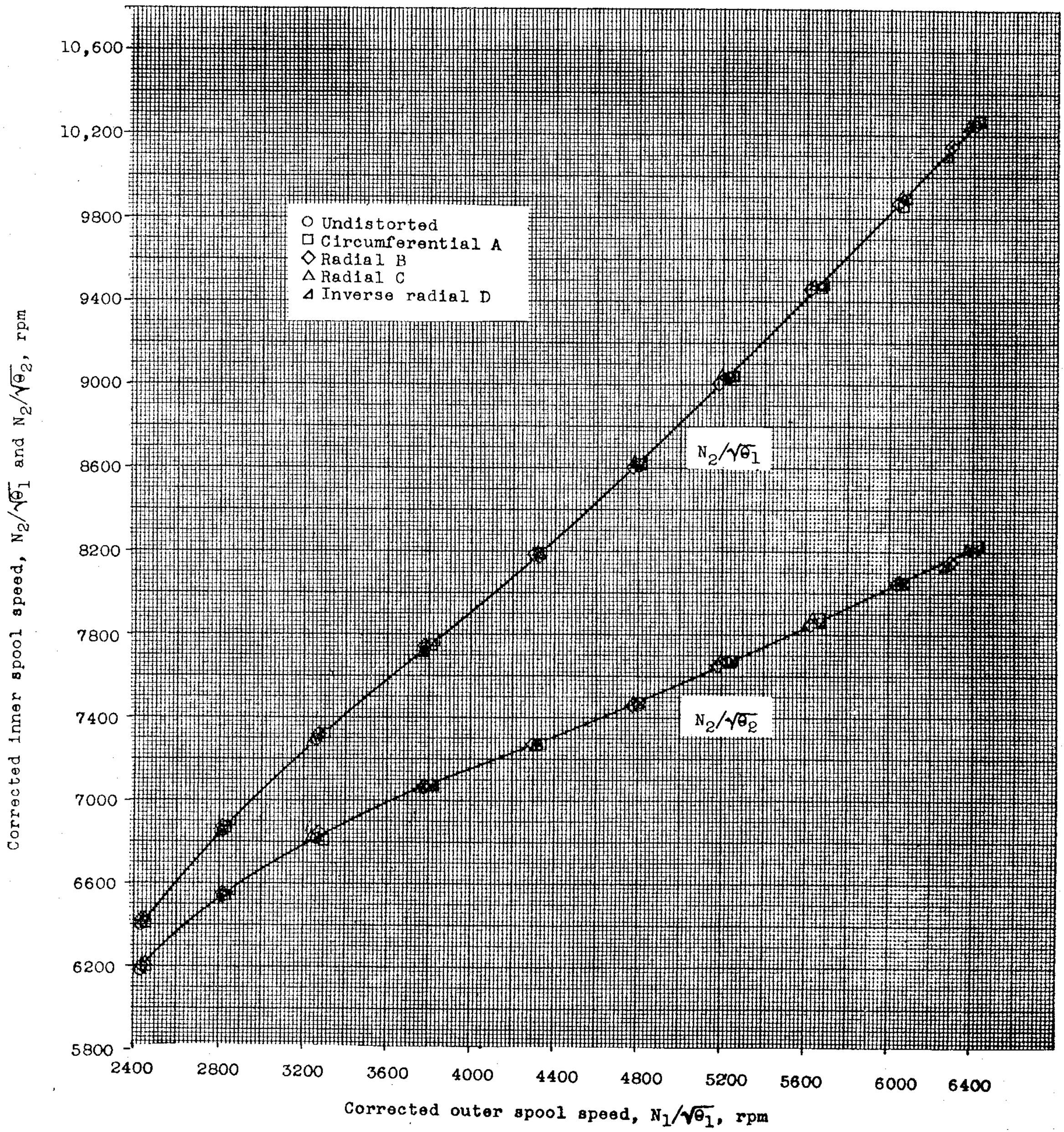

Figure 11. - Variation of corrected inner spool speed with corrected outer spool speed for several inlet pressure distortions. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds open. Engine B.

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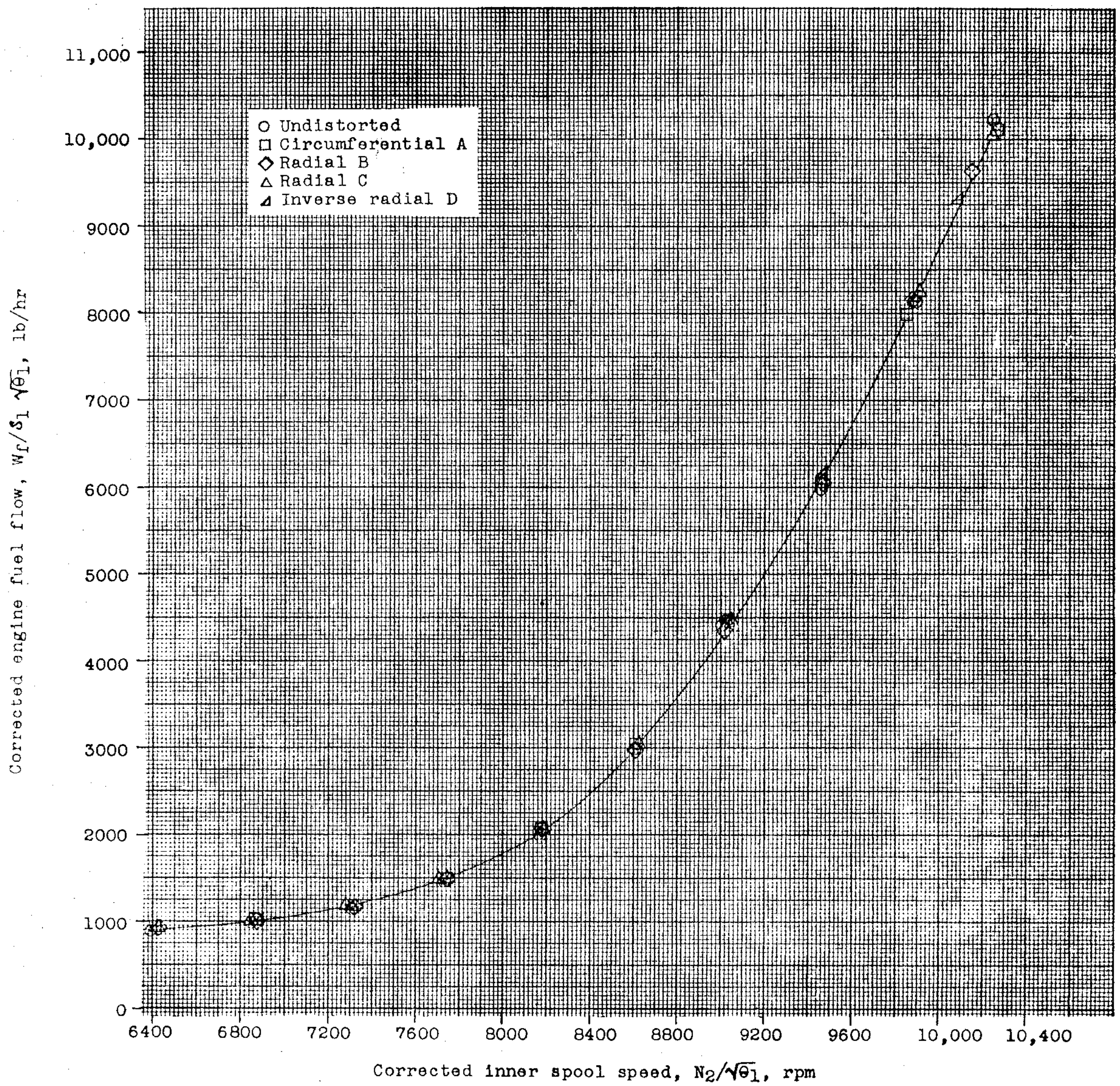

Figure 12. - Engine fuel flow steady-state operating line for several inlet pressure distortions. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds open. Engine B.

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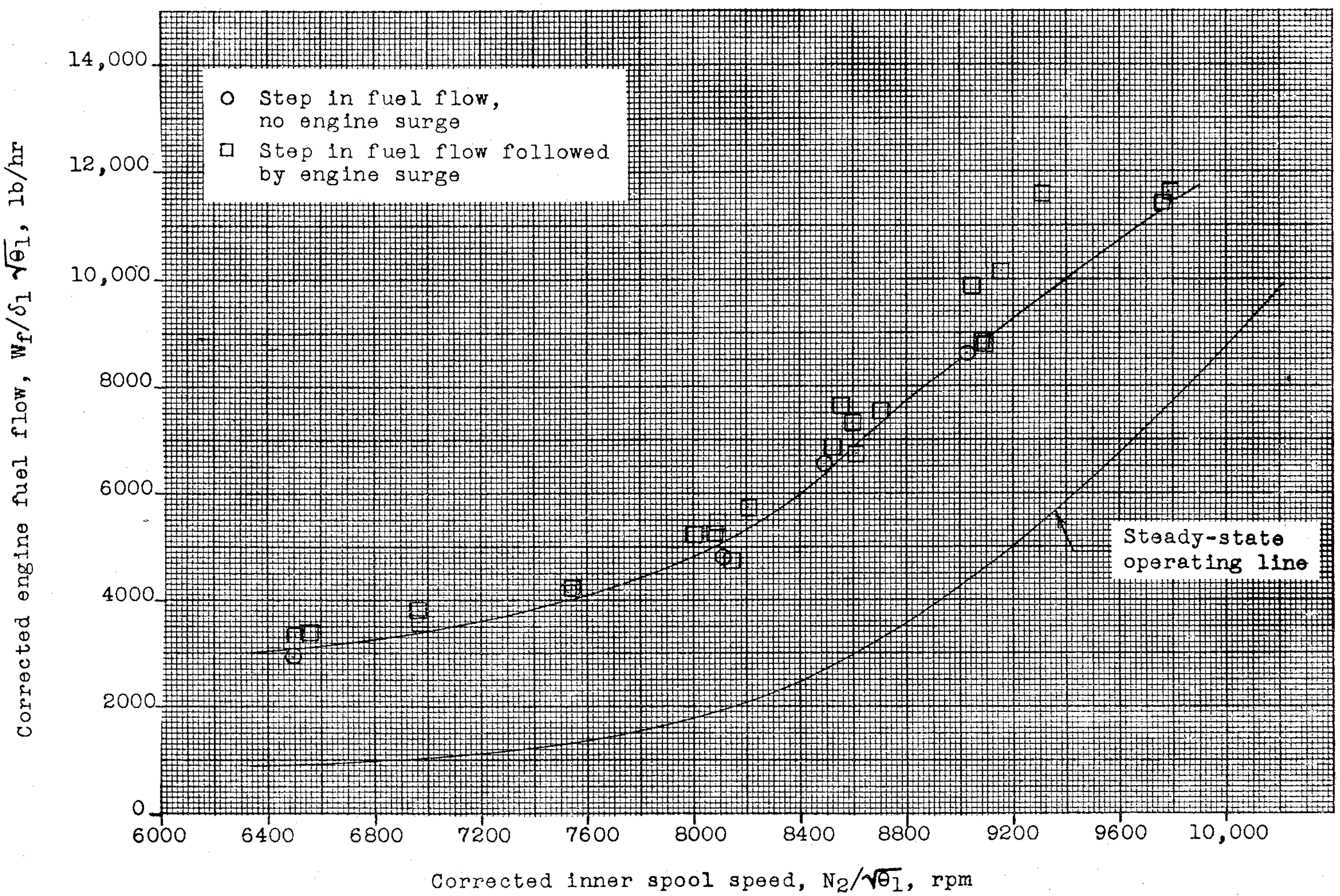

Figure 13. - Comparison of engine fuel flow surge limits with steady-state operating line for uniform inlet pressure distribution. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds open. Engine B.

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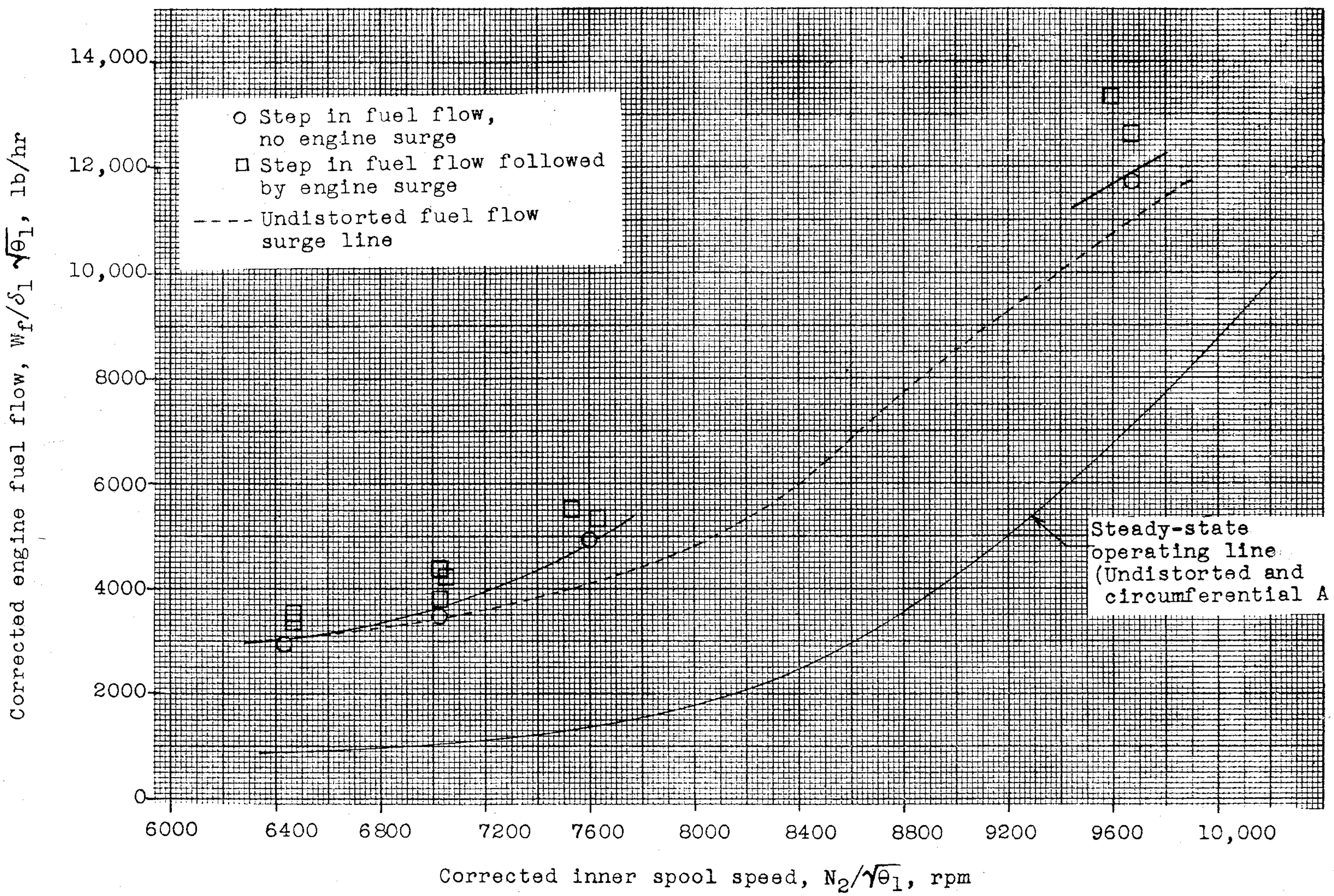

Figure 14. - Effect of circumferential distortion on fuel flow surge limits. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds open. Engine B.

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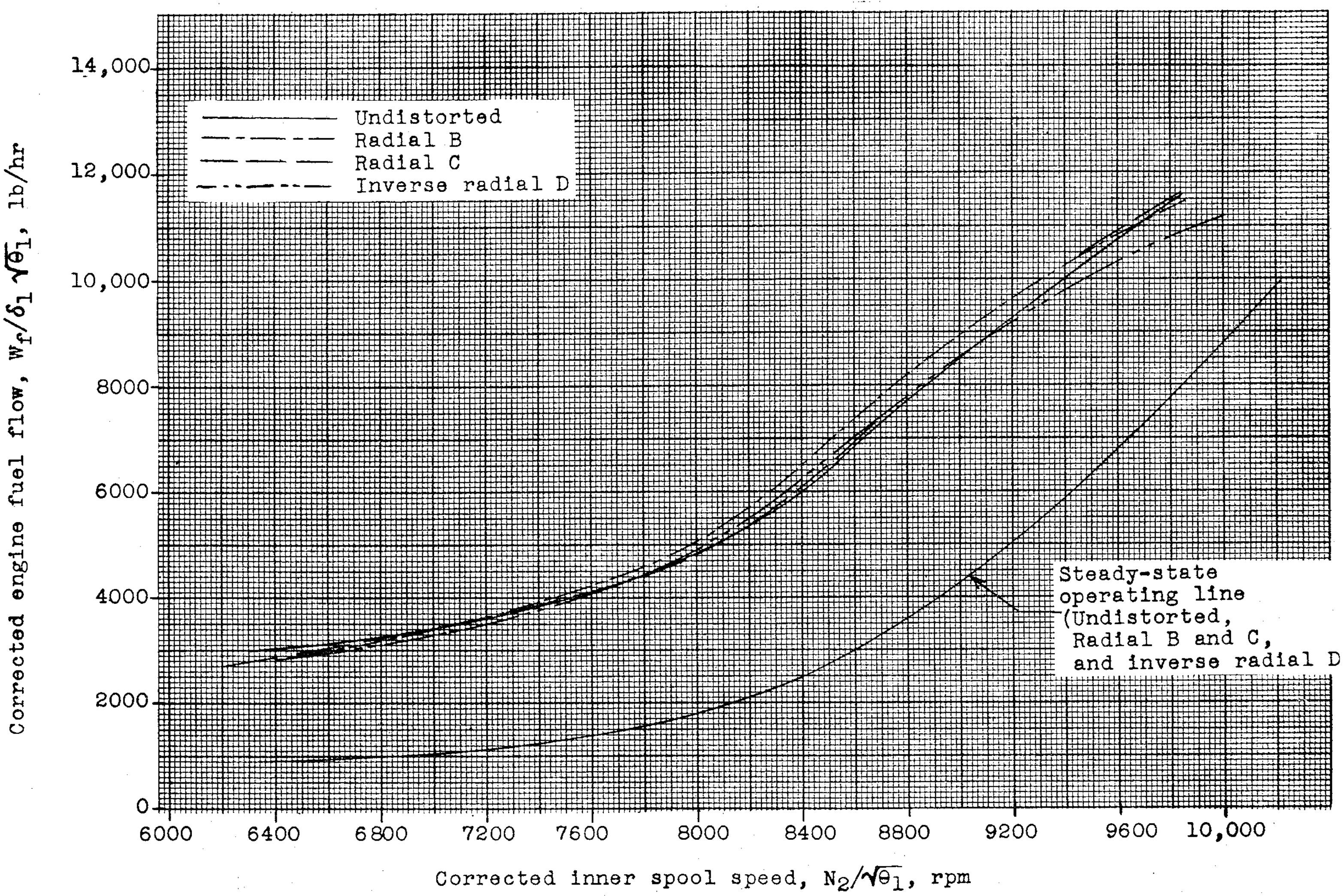

Figure 15. - Effect of radial inlet pressure distortions on engine fuel flow surge limits. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds open. Engine B.

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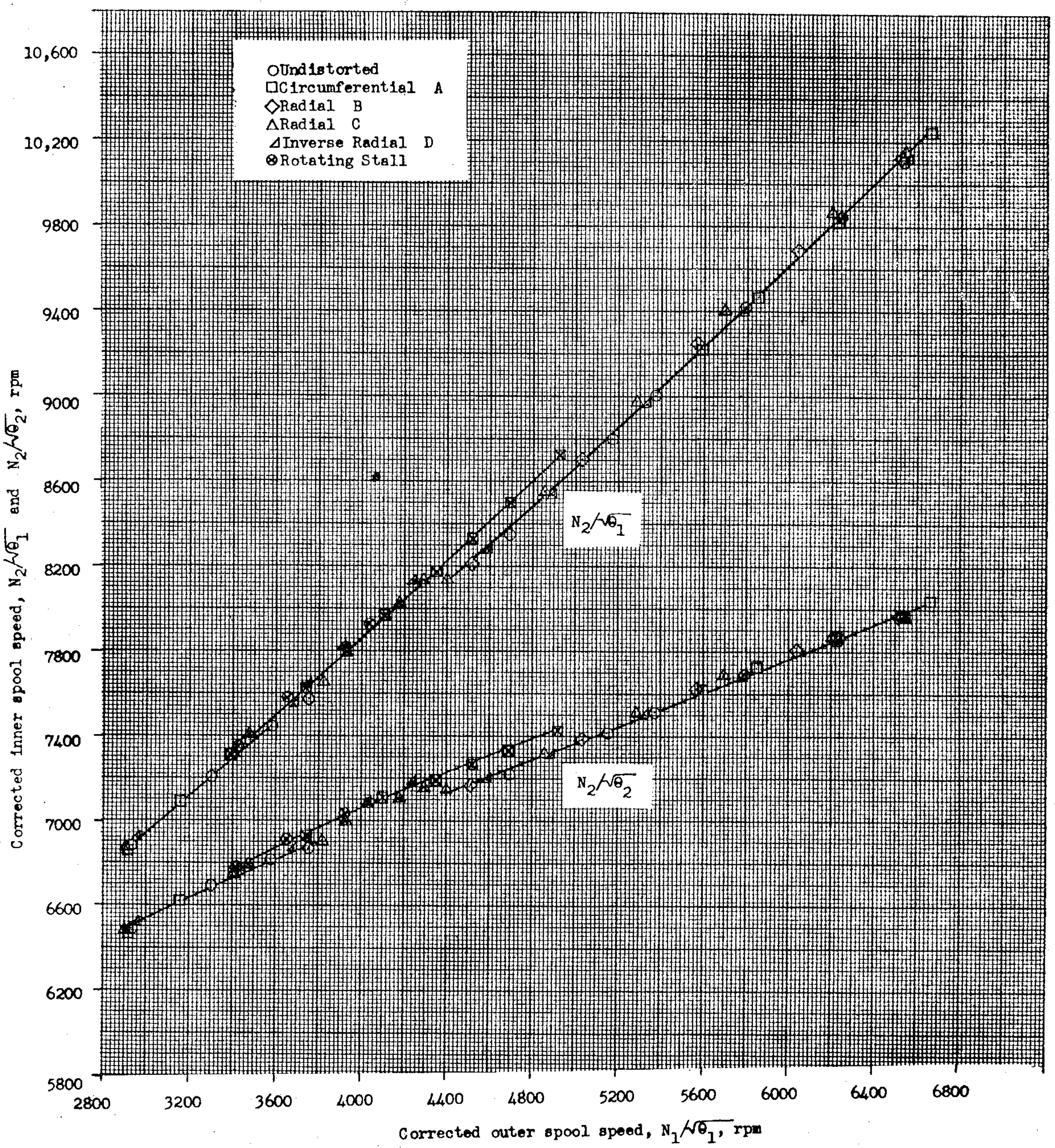

Figure 16. - Variation of corrected inner spool speed with corrected outer spool speed for several inlet pressure distortions. Altitude 35,000 feet. Flight Mach number 0.8. Compressor bleeds closed. Engine B.

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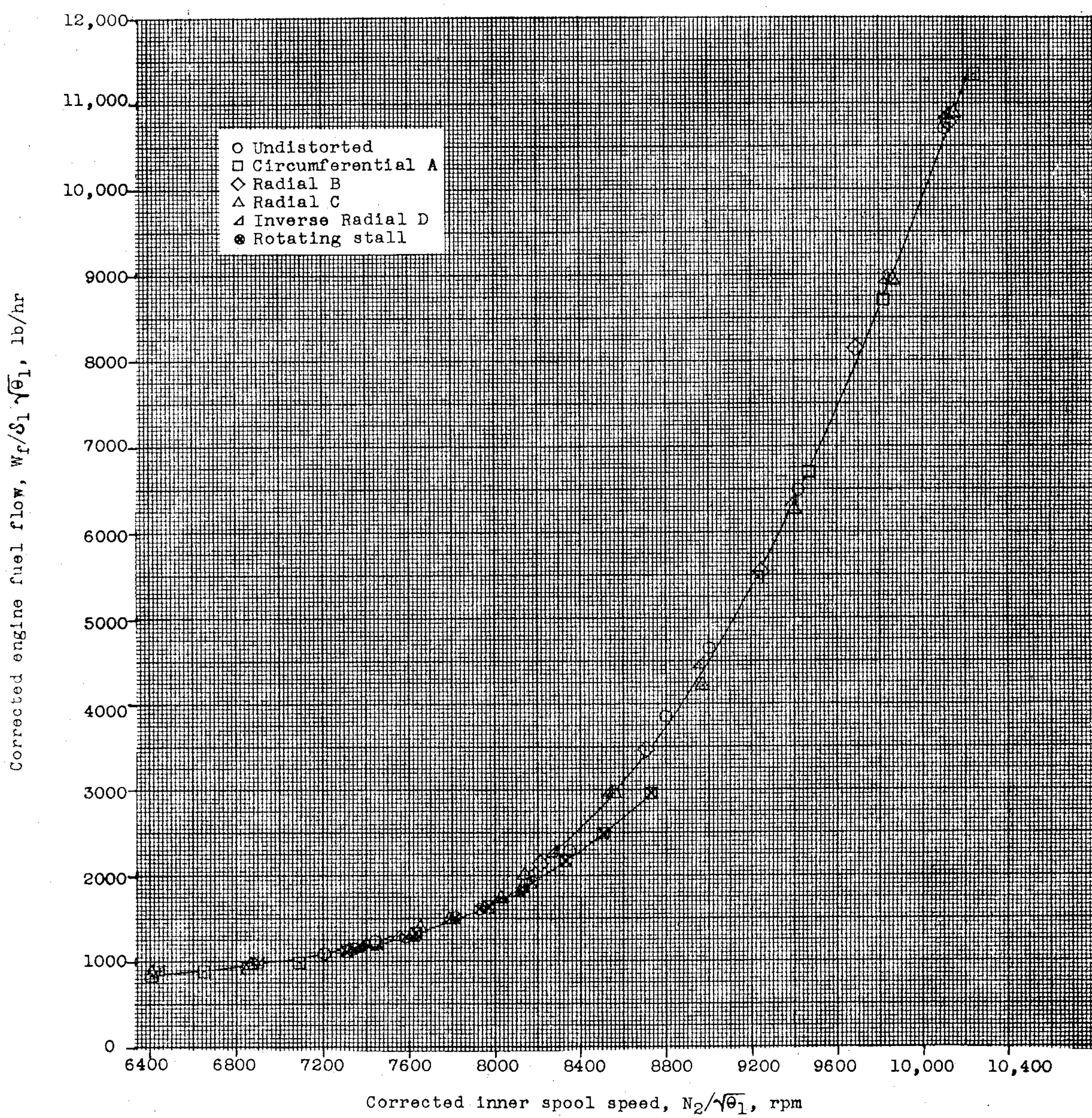

Figure 17. - Engine fuel flow steady-state operating line for several inlet pressure distortions. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds closed. Engine B.

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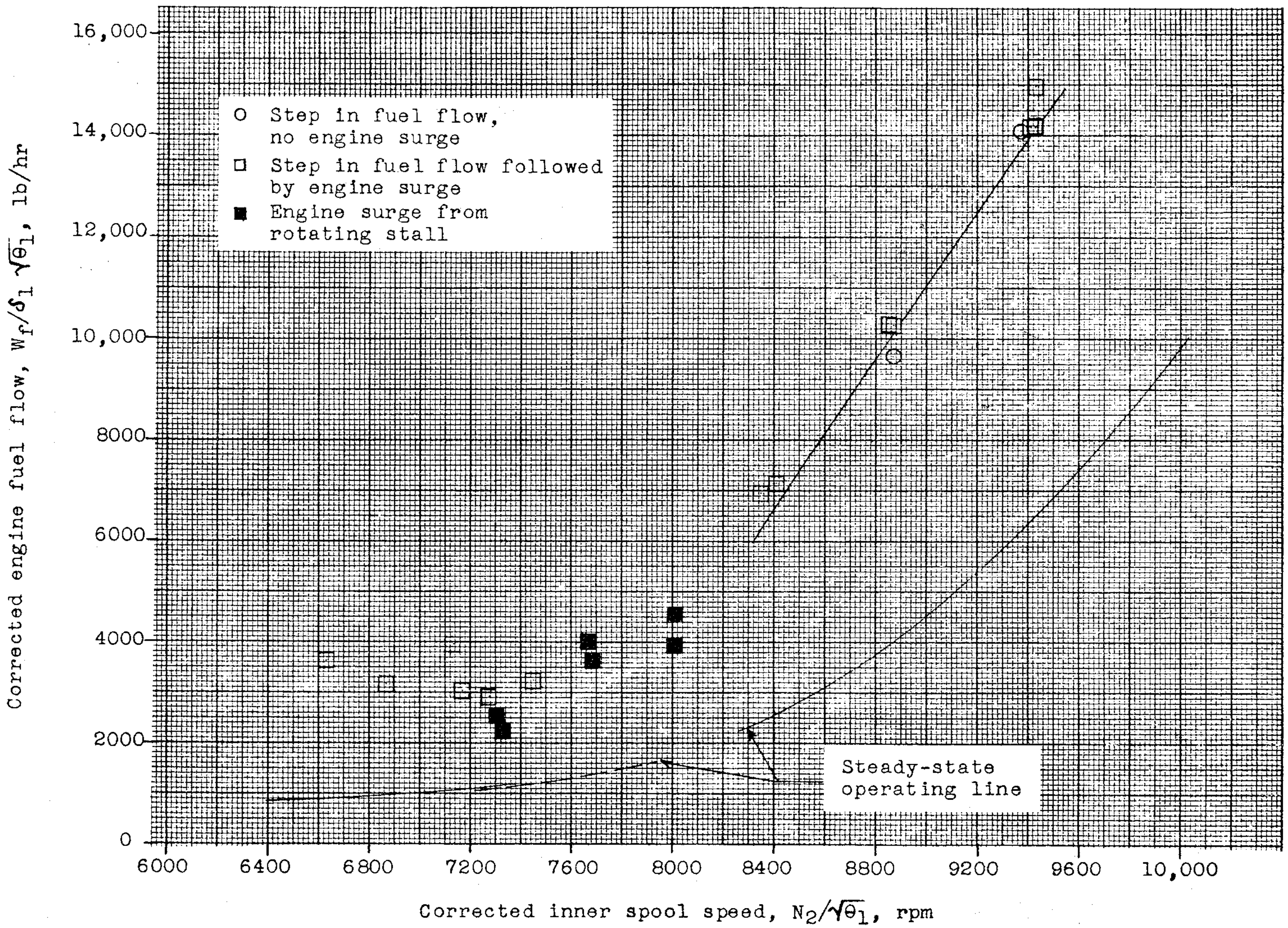

Figure 18. - Comparison of engine fuel flow surge limits with steady-state operating line for uniform inlet pressure distribution. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds closed. Engine B.

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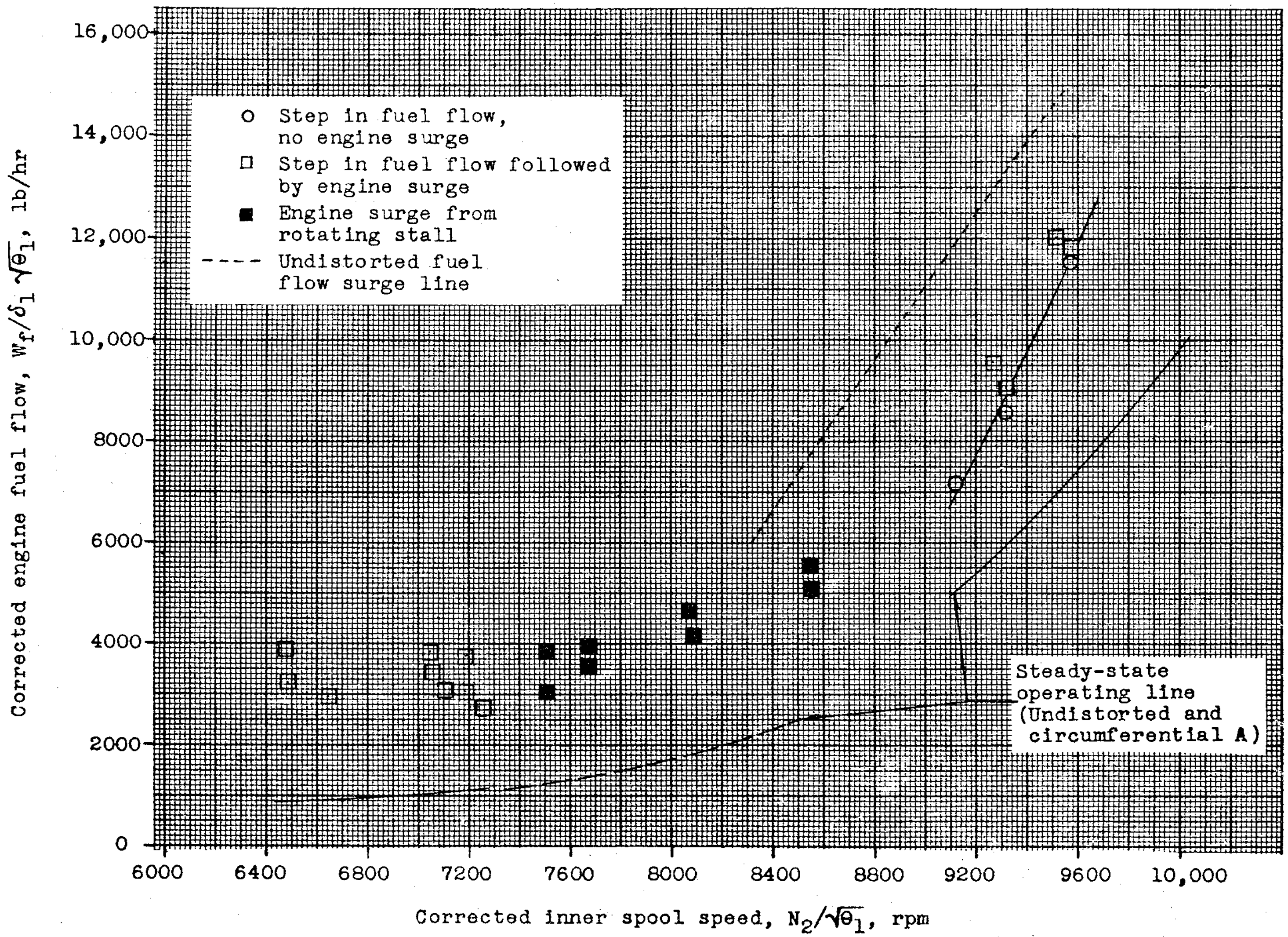

Figure 19. - Effect of circumferential distortion on fuel flow surge limits. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds closed. Engine B.

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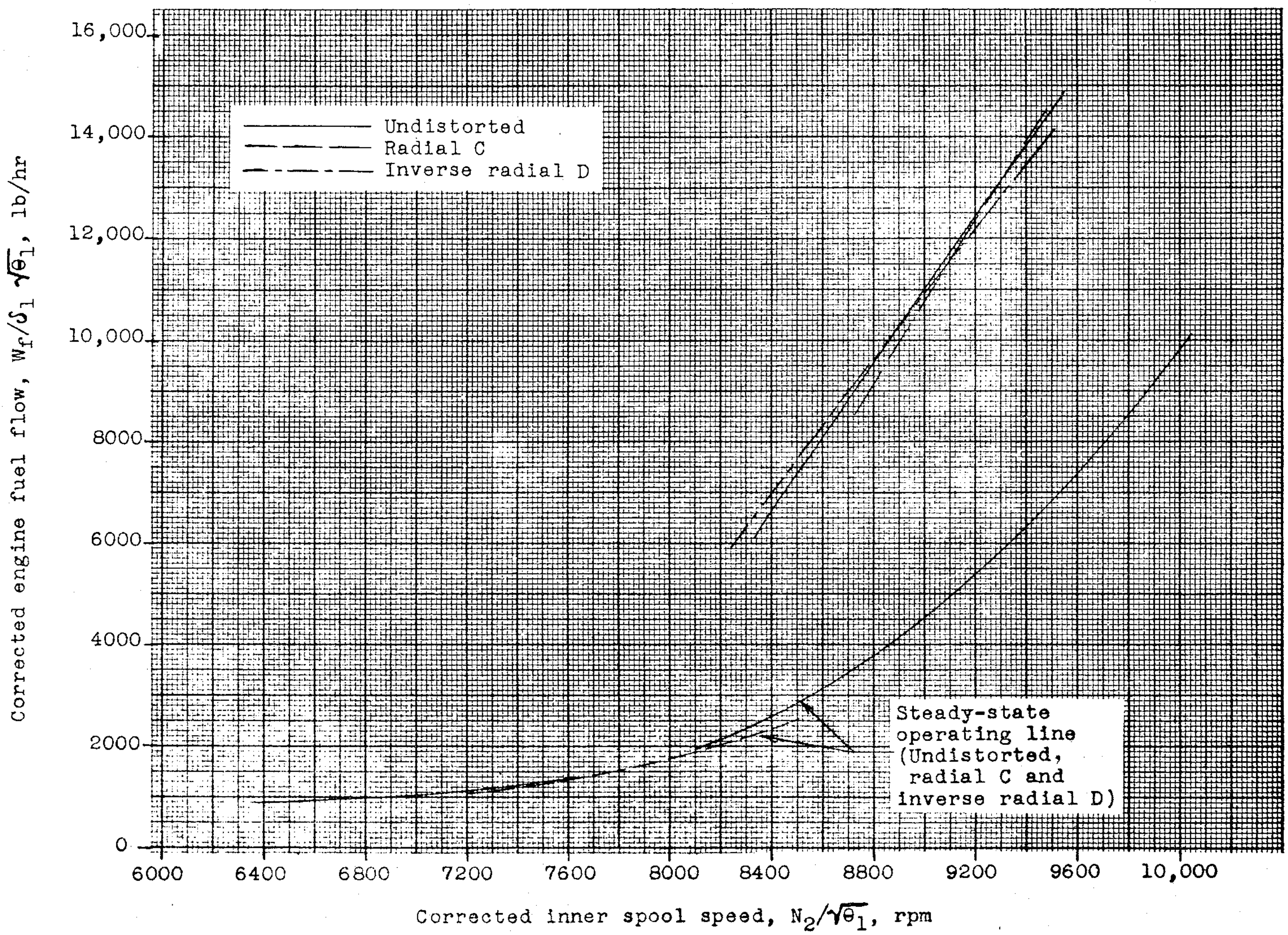

Figure 20. - Effect of radial inlet pressure distortions on engine fuel flow surge limits. Altitude 35,000 feet, flight Mach number 0.8, compressor bleeds closed. Engine B.

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